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Review of VHF Band 1 field strength prediction

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Summary

The Report describes the results of a review of VHF Band I field strength measurements and prediction methods. Most of the measurements were made by the BBC, and many were used in the early Nineteen-sixties to prepare CCIR propagation curves. Modern computational methods have permitted a fuller analysis of the data than has been possible previously. This has led to conclusions about the accuracy of the CCIR prediction method, how it should best be used, and the extent of discrepancies in the existing procedures. In addition, this review examines the BBC's more detailed path loss computerised prediction method. This has the potential to give more accurate results than the CCIR curves, although the program has not yet been developed for operation at Band I frequencies. Finally the report makes proposals for future improvements to these prediction techniques, and considers the possibility of developing a harmonised approach.

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Introduction

The work described here forms part of a larger project intended to review field strength prediction methods used for broadcast service planning in the frequency range 30 to 1000 MHz. It deals with a section of that spectrum which, with the exception of certain assignments for broadcast ancillary services, is no longer allocated to broadcasting in the United Kingdom, namely Band I (40 to 68 MHz). The results are, however, of immediate interest to the U.K. Department of Trade and Industry, and this phase of the work was undertaken partly on their behalf.

The majority of the measured evidence which has been used in this study for comparison with prediction has been extracted from measurements made by the BBC over the past 40 years. Two distinct prediction methods are investigated, the first being the statistical field strength/distance curves published by the CCIR as Recommendation 370[1], and the second is a detailed path loss calculation developed by the BBC[2]. It is expected that the project as a whole will produce some significant comments regarding both of these techniques, and in particular some substantial contributions to CCIR Study Group 5 can be foreseen. An indication of the scope that these contributions might cover is given in this Report.

1. Scope of the Band I review

1.1. General

The work is based on field strength measurements made by the BBC in the frequency range 41.5 MHz to 66.75 MHz. Many of the early measurements were used in preparing propagation curves which were employed at the ITU Broadcasting Conference held in Stockholm in 1961, and these in turn were adopted by the CCIR as Recommendation 370 in 1963. In this review the original data have been re-examined as certain anomalies have become apparent over the years of extensive use of the existing CCIR curves.

The separate comparison with the BBC prediction method is of interest because this is an example of an approach which takes account of the unique features of each propagation path, and which should therefore be capable of achieving more accurate results than can be obtained using the statistical curves.

1.2. The Measurements

Measured evidence for this review has been obtained from two principal sources. For the shorter distances, i.e. for path lengths < 100 km, measurements have been extracted from surveys of BBC Band I television transmitting stations. For the longer ranges, the results have been obtained from various long-distance propagation experiments. Unfortunately there are comparatively few BBC results for the longer ranges, due to the fact that the extensive propagation studies initiated by the Corporation in the late Forties and early Fifties concentrated on the higher frequency bands. However, experiments were also conducted by the then U.K. Post Office and the Directorate of Scientific and Industrial Research, and results from their work have been included here[3].

For the short paths, measurements from ten surveys have been selected, which between them represent about 25% of the total survey work of this type carried out by the BBC at these frequencies. Although a survey is a comparatively routine process intended to determine the coverage of a station rather than for propagation research, these measurements offer a considerable quantity of reliable field strength data. Most of the measurement work was carried out using a receiving antenna mounted at some convenient height upon a survey vehicle, usually between three and five metres above ground level, the output of the receiver being fed to a chart recorder driven from the vehicle transmission. A survey of a high-power station would result in an average of about 3000 km of road measurement, although some of the larger stations required three or four times this amount. The main operating characteristics of the stations selected for this study are shown in Table 1.

For the long paths, results have been obtained from the experiments listed in Table 2. These fall into three categories of path – overland, mixed, and oversea – and together represent a total measuring time of about 15 years.

The receiving sites chosen for these long distance measurements were generally in open country, as far as possible free from local obstruction. This

Station	Frequency (MHz)	Polarization	Max. e.r.p. (kW)
Ashkirk	41.5	Vertical	15
Crystal Palace	41.5	Vertical	169
Dover	48.25	Vertical	1.35
Holme Moss	48.25	Vertical	100
North Hessary Tor	48.25	Vertical	27.5
Meldrum	58.25	Horizontal	17.3
Pontop Pike	63.25	Horizontal	12
Rowridge	53.25	Vertical	85
Sutton Coldfield	58.25	Vertical	100
Wenvoe	63.25	Vertical	98

Table 1 : Details of Transmitting Stations

was to permit the detection of an often weak signal, and a site variation factor was derived separately in order to give a result for "average terrain conditions". The method of derivation differed slightly between the U.K. organisations participating in the work, but the effect of this has not been investigated. It is noted at this stage that recent discussion internationally regarding this factor has revealed the need for some degree of standardisation, because different techniques can affect the conclusions.

In addition to the experiments listed in Table 2, which were intended to investigate the effect of the troposphere on the temporal behaviour of the signal, some work has been carried out by broadcasting organisations into the influence of temperate zone sporadic E propagation[4]. The results of this work are also summarised in this report.

1.3. The Predictions

1.3.1. CCIR

As mentioned above, the statistical field strength/distance curves are published in Recommendation 370. They also form the basis for a further set of curves which are for use for land mobile service planning, and which appear as Report 567 (Methods and Statistics for estimating field-strength values in the land mobile services using the frequency range 30 MHz to 1 GHz). Supporting material is also found in Report 239 (Propagation Statistics required for broadcasting services using the frequency range 30 to 1,000 MHz) and Report 228 (Measurement of field strength for VHF and UHF broadcast services, including television). These, and other reports related to the same subject appear in Section 5D (Aspects relative to the terrestrial broadcasting and mobile services) of CCIR Volume V – Propagation in Non-ionized Media. The main objective of this Section of the Volume is to provide practical, uncomplicated propagation statistics for spectrum planning purposes.

The propagation curves were based upon many thousands of measurements made in Europe and the USA. They were obtained in the Forties and Fifties, a time when the demand for the development of broadcasting services was extremely high. The problems of acquiring the data in order to meet demanding time scales, and the difficulties of manual analysis, meant that little time could be spent on examining reasons for differences between contributions from several sources. Not surprisingly, various anomalies have become apparent over years of intensive use. Furthermore, certain modifications have been introduced from time to time, and some of these have led to inconsistencies within the technique. In 1983, IWP 5/5 suggested that the original data used to prepare the propagation curves should be re-examined. Fortunately, many of the BBC measurements which were contributed still exist, and more detailed analysis than has previously been possible can now be undertaken[5].

1.3.2. BBC

The BBC prediction technique was originally devised for use at UHF – to assist with the implementation of the plan for a four-programme television network in the U.K. using these frequencies. It is a path-loss method, in which the attenuation along a profile is estimated, given information about the terrain from a data bank. Although there have been some attempts to modify the program so that it can be used at lower frequencies, these have been limited. An outline of the prediction technique is given in the Appendix.

2. Results

2.1. Comparison with the CCIR Prediction

2.1.1. Recommendation 370

As mentioned above, this Recommendation forms the basis of the CCIR prediction technique published in Section 5D of Volume V. It shows the decay of field strength with distance from the transmitting antenna, and one set of curves covers the three VHF bands. They represent the field strength values exceeded at 50% of the locations at a receiving antenna height of 10 m a.g.l., and the Recommendation also provides an indication of the variation of field strength about this median value. The subject of location variation is complex, and is dealt with later; at this stage it is only necessary to

Path and Transmitter	Frequency (MHz)	Receiving Site		Distance (km)	Duration (months)
Overland					
Crystal Palace	41.5	East Harptree	(PO)	179	13
,,	,,	Banbury	,,	110	12
,,	,,	Halwell	,,	286	9
Alexandra Palace	,,	Castleton	,,	203	38
,,	45.0	Leeds	(BBC)	267	25
,,	,,	Largoward	,,	548	6
North Hessary Tor	48.25	Mursley	,,	272	18
,,	,,	Banbury	(PO)	250	9.
Holme Moss	,,	Kingswood	(BBC)	273	3
,,	,,	Reigate	,,	282	3
,,	,,	Hookwood	,,	286	1
,,	,,	Arncliffe	(PO)	102	5
,,	,,	Banbury	,,	169	6
,,	,,	Slough	(DSIR)	243	6
Rowridge	53.25	Banbury	(PO)	152	12
Sutton Coldfield	58.25	Caversham	(BBC)	138	18
,,	,,	Mursley	,,	100	18
,,	,,	Largoward	,,	412	14
,,	,,	Portreath	,,	352	9
,,	,,	Redruth	,,	353	4
,,	,,	Castleton	(PO)	144	16
,,	,,	Green Hailey	(DSIR)	120	22
,,	,,	Slough	,,	151	18
,,	,,	Kingswood	(BBC)	183	5
,,	,,	Reigate	,,	191	3
,,	,,	Hookwood	,,	195	1
Pontop Pike	63.25	Banbury	(PO)	315	24
Wenvoe	,,	Caversham	(BBC)	161	18
,,	,,	Mursley	,,	179	18
Peterborough	,,	Caversham	,,	122	18
Mixed Paths					
Caen	41.25	Tolsford	(PO)	267	17
Alexandra Palace	41.5	Douglas	,,	411	9
Divis	,,	Leswidden	,,	499	14
North Hessary Tor	48.25	Cork	,,	350	12
Blaen Plwyf	53.25	Holyhead	,,	113	8
Sutton Coldfield	58.25	Redmoss	(BBC)	502	14
Pontop Pike	63.25	Murcar	(PO)	261	8
Netherburton	,,	Scousburgh	,,	147	8
Oversea:					
Bergen	42.0	Scousburgh	,,	363	22
Blaen Plwyf	53.25	Dublin	,,	175	12
Rowridge	,,	Stoke Fleming	,,	163	10
Les Platons	,,	Stoke Fleming	,,	161	6
Les Platons	,,	Leswidden	,,	271	14

Table 2 : Long-distance recording experiments

note that the curves have been based on median figures.

For distances up to about 100 km, measured results were obtained from the ten surveys listed in Table 1. Median values were extracted for 1605 built-up areas, these varying in size from villages to cities. In each case predictions were obtained from the CCIR curves, and compared with the measurement. The result of the comparison, in which the

ratio Prediction/Measurement is shown in terms of the mean difference and the standard deviation of the distribution, is given in Table 3.

Station	Number of Medians	Ratio, Prediction/ Measurement Mean Difference (dB)	Standard Deviation (dB)
Ashkirk	66	12.1	8.3
Crystal Palace	153	7.6	5.0
Dover	30	6.7	4.8
Holme Moss	538	3.6	11.0
North Hessary Tor	127	6.6	9.2
Meldrum	42	10.2	8.6
Pontop Pike	97	8.1	8.0
Rowridge	120	2.9	3.7
Sutton Coldfield	220	5.1	6.1
Wenvoe	212	12.1	9.3

Table 3: Comparison of Recommendation 370 prediction with measured median values.

A discussion of the results is contained in Section 3 of this Report, but at this stage it is noted that in all cases the prediction overestimates the field strength which was measured. The average ratio Prediction/Measurement for all 1605 results is + 6.3 dB.

For the longer ranges, i.e. beyond 100 km, a similar comparison between predictions derived from the CCIR curves and measurements obtained from the experiments listed in Table 2 gave the results shown in Table 4.

About 75% of the measured data used for the long range comparison was available when the CCIR curves were produced in 1963. In respect of the overland and oversea results therefore this check is effectively only a comparison of the curves against much of the data upon which they were originally based. The errors are comparatively small but it must be emphasized that very few measurements are available. The recent investigation has also revealed one area of concern – this relates to the derivation of site variation factors (svf), already mentioned in the previous section. In pursuing this analysis, the svf's quoted in the original results have been used, but many of these were estimated at the time of measurement, and certain inconsistencies are obvious. It would seem a more reliable technique would be to determine the svf on the basis of the receiver terrain correction (see Section 2.1.2), but of course this concept had not been introduced at the time the propagation curves were produced.

One other feature of Recommendation 370 was checked in this phase of the calculation, namely the variation of field strength with receiving location. Figure 5 of the Recommendation (Page 219 of Volume V, 1982), gives the ratio of field strength for a given percentage of the receiving locations to the value for the median condition. It is a somewhat imprecise statement, in that no dimension is given for the area represented by the distribution, and a log-normal law has been assumed. For practical use in connection with a particular receiving site, a subjective assessment has to be made concerning the relationship of the site to the median value. The CCIR curve was in fact based upon results from built-up areas of various sizes, many of which are included in this review. The CCIR figure shows a single curve for the band 30 to 250 MHz, and this has been checked by comparison with survey measurements. Of the ten surveys used in the short-range comparison, data concerning the field strength distribution in each town measured was readily available for seven of the transmitters, and the standard deviation averaged for each of these is shown in Table 5. The average of all the results is 6.0 dB, and this can be compared with the standard deviation of 8.0 dB derived from the CCIR figure. Bearing in mind that location variation increases with frequency, this result seems not inconsistent, because the CCIR curve presents the situation in Bands I, II and III. There are, however, many observations to be

	1% Time		5% Time		10% Time		50% Time	
Path	Difference dB	Standard Deviation dB	Difference dB	Standard Deviation dB	Difference dB	Standard Deviation dB	Difference dB	Standard Deviation dB
Overland	0	6.9	+ 2.0	7.3	+ 1	6.9	+ 1	6.6
Mixed*	+ 2	5.8	− 1.0	4.4	− 2	3.1	− 2	7.1
Oversea*	− 2	6.3	− 5.0	5.5	− 4	6.2	0	6.5

* Statistics doubtful because of small sample size.

Table 4: Comparison of Recommendation 370 prediction with measurements from long range experiments.

made on the question of location variation as mentioned before, and these are discussed later.

Transmitting Station	Standard Deviation (dB)
Dover	2.8
Crystal Palace	3.5
North Hessary Tor	4.8
Holme Moss	6.5
Pontop Pike	7.0
Ashkirk	7.7
Meldrum	9.7

Table 5 : Standard deviation of field strength distribution in towns.

2.1.2. Report 239

Whereas Recommendation 370 provides the median values of measurements made within small areas at stated ranges from the transmitting station, the field strength at a particular location can be deduced if the "receiver terrain correction" is used. This is described in sub-section 4.2 of CCIR Report 239. The concept was originally introduced by the BBC for U.K. planning about 20 years ago, and was intended to take some account of the unique properties of each propagation path. Study had shown that terrain in the immediate vicinity of the receiving site was an important factor in determining the field strength, and the correction curve to be applied to the Recommendation 370 prediction was derived from measurements.

For the investigation carried out here, field strength measurements at precise locations were required. A total of 260 receiving sites was selected from the ten surveys. In addition, detailed measurements were extracted from four other built-up areas – Chelmsford, Oxford, Swansea and Bristol – from which a further 290 reception sites were chosen. The total of 550 sites was then separated into three categories – urban, suburban and rural – and Table 6 shows the results of comparing these measurements with predictions obtained using Recommendation 370–4 in conjunction with the receiver terrain correction of Report 239–5.

The general conclusion from the results shown in Table 6 is that the application of such a correction is a useful supplement to the basic propagation curves. The results, which it must be remembered are an analysis of prediction for precise locations, compare very favourably with the comparison of median values, given in Table 3. Furthermore, as the correction is capable of predicting the field strength at a particular location, the results give a more realistic assessment of field strength distribution over an area than is possible using the location variation curve discussed in 2.1.1.

Receiving Sites	Category and Number	Ratio, Prediction/Measurement (dB) Mean Difference	Standard Deviation
Survey measurements	Urban (52)	5.0	7.0
	Suburban (160)	1.1	7.3
	Rural (48)	−1.7	7.0
Chelmsford	Urban (5)	5.0	*
	Suburban (14)	3.9	2.9
	Rural (4)	4.3	*
Oxford	Urban (10)	5.7	1.2
	Suburban (35)	−0.5	5.4
	Rural (22)	−0.7	4.9
Swansea	Urban (11)	1.4	2.7
	Suburban (87)	−5.1	7.4
	Rural (2)	1.7	*
Bristol	Urban (15)	3.8	5.5
	Suburban (57)	−3.5	5.4
	Rural (28)	−5.5	6.2

*Sample too small to quote realistic figure.

Table 6 : Use of recceiver terrain correction.

2.2. Comparison with the BBC Prediction

The BBC path loss prediction technique has not so far been adapted for use at Band I frequencies, and for this reason the results were expected to be disappointing. However, the ability of the method to take account of details in each propagation path is a considerable advantage, and the comparisons reported below are generally better than anticipated.

The prediction produces results for specific locations and in this respect is directly comparable with the receiver terrain correction technique of Report 239. In the first comparison, therefore, the same 550 measurements used to check this correction, reported in 2.1.2. have been used. Table 7 shows the results, which are for the shorter range propagation paths.

For the longer ranges, measurements for comparison have been obtained from the experiments listed in Table 2. Field strengths over these paths have been calculated using the BBC program, and the result of the comparison is shown in Table 8.

It will be seen that the BBC program, in its present form, is overestimating the field strengths, and the scatter is greater in the long-range paths (Table 8) than in calculations for the shorter distances (Table 7).

Receiving Sites	Category and Number	Ratio, Prediction/Measurement (dB) Mean Difference	Standard Deviation
Survey measurements	Urban (52)	5.5	7.0
	Suburban (160)	2.6	7.1
	Rural (48)	1.1	7.0
Chelmsford	Urban (5)	7.8	*
	Suburban (14)	4.9	3.7
	Rural (4)	7.2	*
Oxford	Urban (10)	12.4	1.6
	Suburban (35)	5.3	5.4
	Rural (22)	5.3	5.2
Swansea	Urban (11)	2.0	3.4
	Suburban (87)	−4.0	7.5
	Rural (2)	6.8	*
Bristol	Urban (15)	3.5	6.3
	Suburban (57)	−2.5	5.2
	Rural (28)	−3.8	6.0

*Sample too small to quote realistic figures.

Table 7 : Use of BBC path loss prediction program.

	1% Time (dB)		5% Time (dB)		50% Time (dB)	
Path	Difference	Standard Deviation	Difference	Standard Deviation	Difference	Standard Deviation
Overland	+6.0	10.4	+2.0	9.1	+5.0	7.4
Mixed*	+7.0	7.6	+4.0	6.6	+5.0	8.6
Oversea*	+2.0	6.4	+1.0	5.1	+2.0	6.4

*Statistics doubtful because of small sample size.

Table 8 : Comparison of BBC prediction with measurements from long-range experiments.

3. Other observations

3.1. General

This section contains further comments on the results described in Section 2, and observations on other aspects of the study. Various problems in the prediction techniques are identified here, but so far the majority of these have not been investigated in depth. However, possibilities for improvement are discussed in Section 4.

3.2. Height above mean terrain

In the CCIR prediction the effect of increasing the height of the transmitting antenna is measured by the "height above mean terrain" parameter. This is the altitude of the antenna above the mean level of the terrain within the range 3–15 km from the transmitting mast. In Recommendation 370, propagation curves are given for a range of heights, having octave relationships and extending from 37.5 to 1200 m above mean terrain. In preparing the

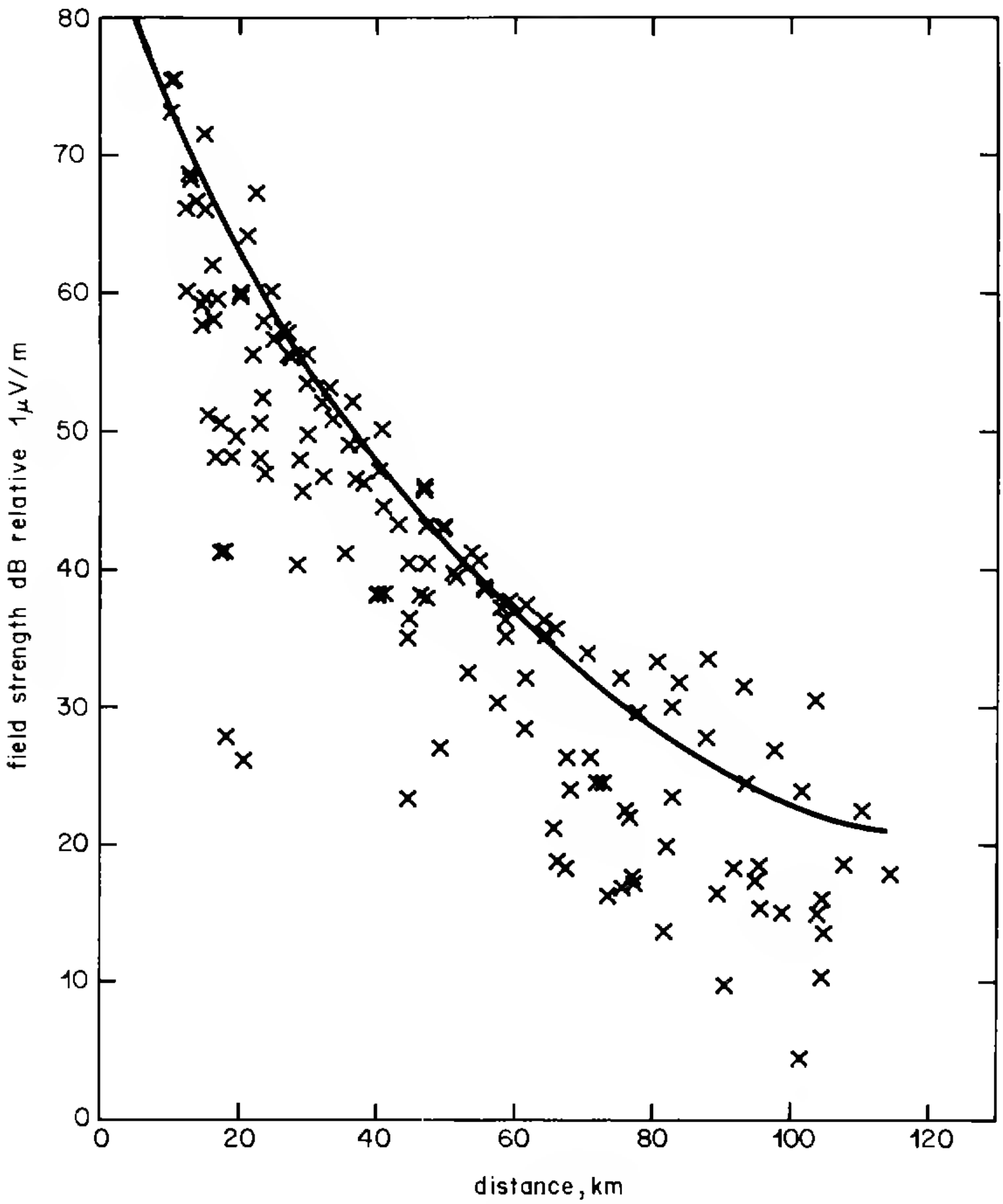

Fig. 1 – Field strength measurements (50% locations) as a function of distance for height above mean terrain of 150 m.

original curves, the effect of height was calculated assuming a smooth plane earth to exist between the terminals, and some support for this assumption was derived from measurements. However, a fuller comparison against the measurements used in this study is not so encouraging. Figures 1, 2 and 3 are plots of measured medians against the appropriate CCIR curves, and these results suggest the precision implied by the height above mean terrain concept is illusory. Similarly, a small sample of the many thousands of transmitting antenna height gain experiments carried out by the BBC during the site test work fails to support the height gain figures proposed in the curves, and demonstrates that height gain is determined by many factors in the overall path – not just a section of it.

3.3. The Δh parameter

This parameter is specified in Recommendation 370 for the purposes of defining the degree of terrain irregularity. It is the difference in heights exceeded by 10% and 90% of the terrain in the range 10 to 50 km from the transmitter. It is not intended for use

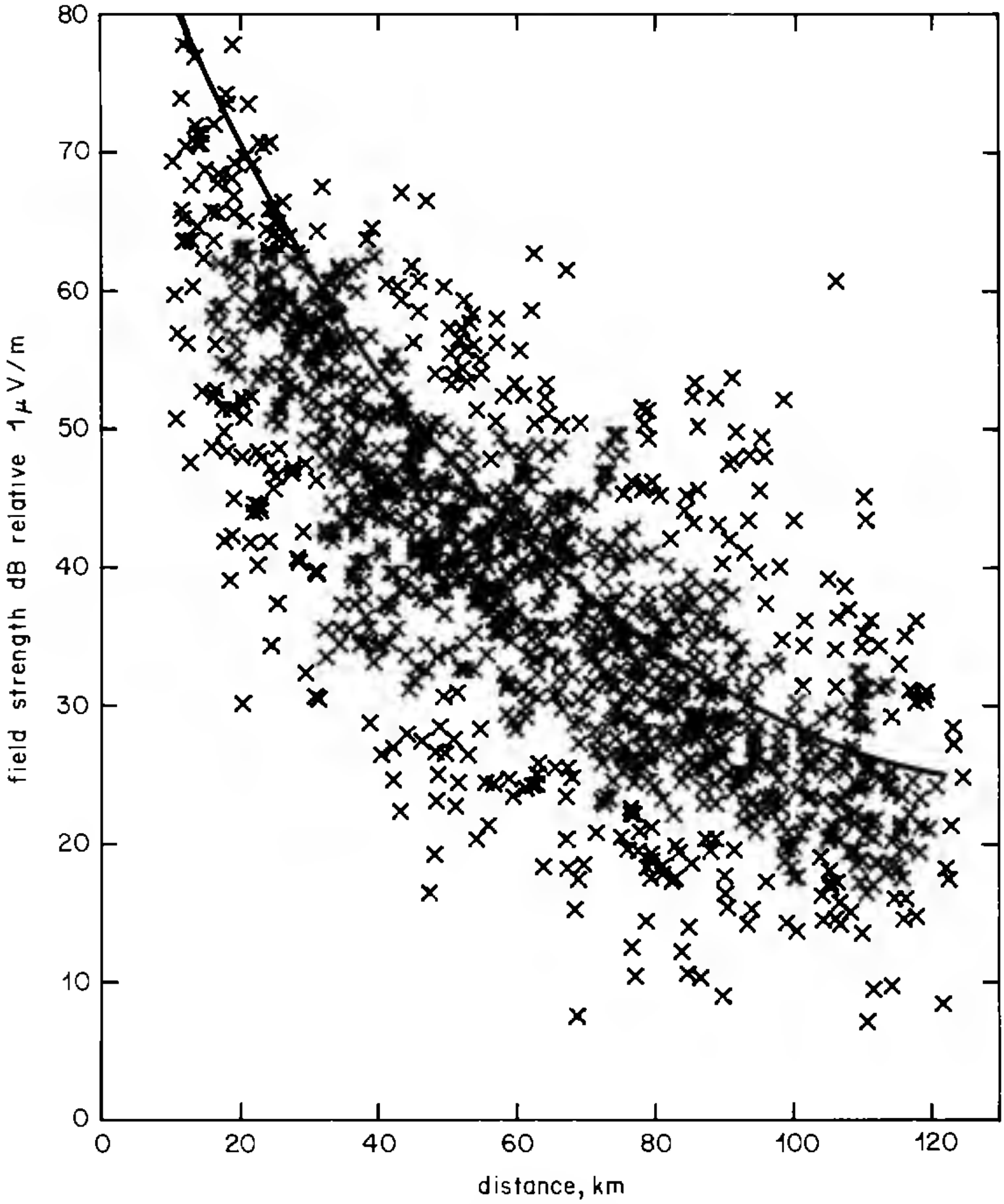

Fig. 2 – Field strength measurements (50% locations) as a function of distance for height above mean terrain of 300 m.

below 80 MHz, but it was derived for each of the 1605 propagation paths examined in Section 2.1.1. of this report. There was some indication that the ratio between prediction and measurement increased with terrain roughness, and indeed application of the Δh correction to these Band I results reduced the mean difference shown in Table 3 from 6.3 dB to 1.4 dB. There was, however, a substantial increase in the scatter of the results (the standard deviation increased from 8.2 dB to 11.6 dB), and it was concluded that this correction is not the solution to this particular discrepancy; subsequent work revealed a more likely explanation is the receiving antenna height gain factor, as discussed in the next Section. It is noted that similar work on Band II also suggested the Δh correction was inappropriate at these frequencies.

However, the Δh study raised one other interesting point. The average value for this parameter derived for the transmitting stations considered ranged from 43 m to 249 m, with an average of 140 m. Only one station (Dover) had a Δh less than the 'typical' figure of 50 m used as a datum for the

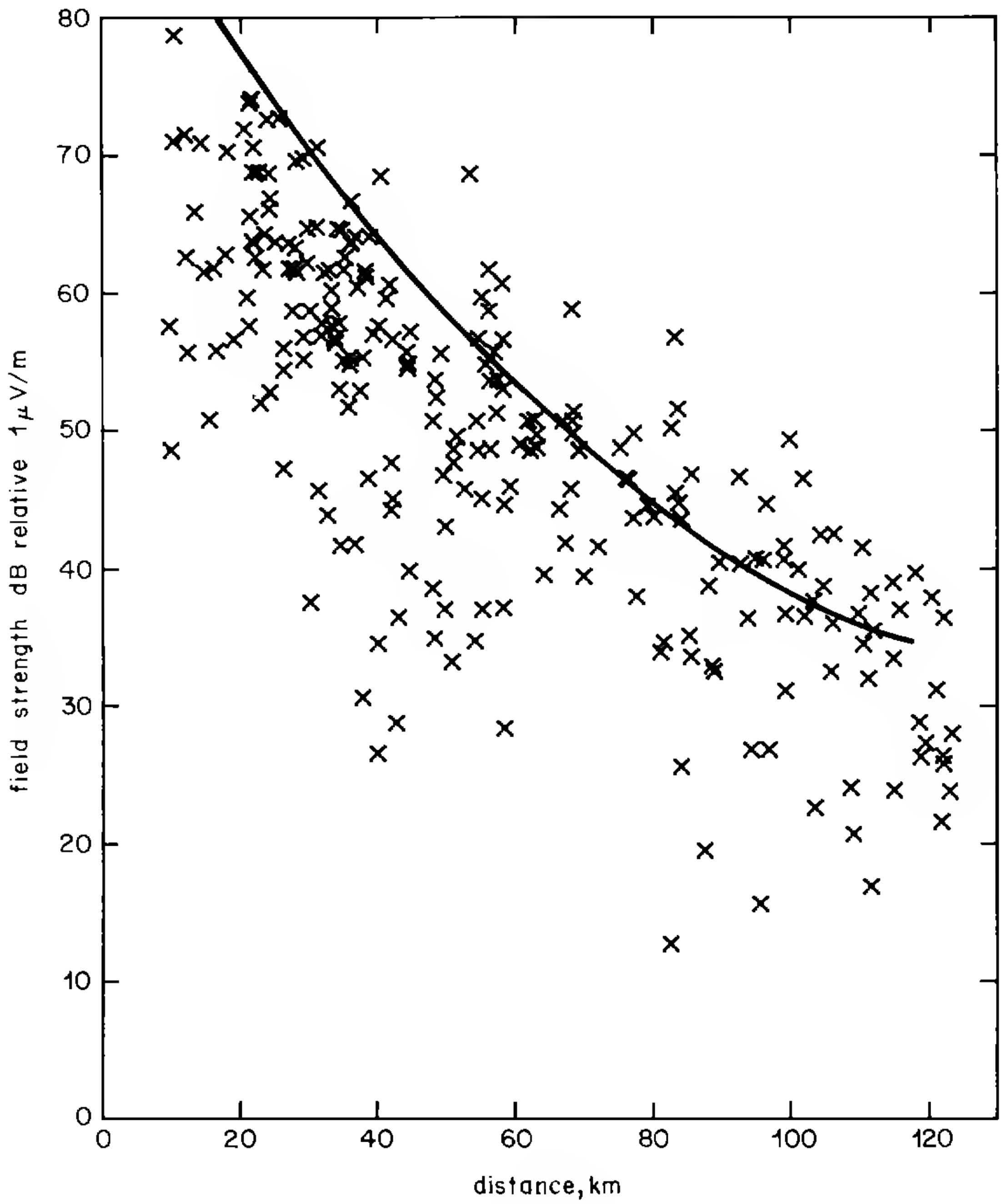

Fig. 3. – Field strength measurements (50% locations) as a function of distance for height above mean terrain of 600 m.

CCIR curves. This fact is, as already mentioned, irrelevant to this Band I study, but has implications for similar work on results for higher frequencies.

3.4. Measurement datum

The following text is illustrated by Figure 4.

The use of a standard height for the receiving antenna of 10 m a.g.l. in the expression of field strength requires the correction of survey measurements of the type made during the course of Band I work. Most of these, as described in Section 1.2, were made using a receiving antenna mounted at a height of between three and five metres above ground level. Checks were made to determine the height gain which might be expected to occur, but unfortunately the number of these was limited, due to the practical difficulties of carrying out such measurements. For practical reasons the majority of these checks were carried out at comparatively open locations, and the results showed that in such areas a linear height gain was applicable (G_M). As can be seen from Figure 4, this height gain correction was applied both to rural and urban measurements, producing the results assumed to exist at 10 m a.g.l. (R_A) and (U_A) respectively. Closer analysis of what little evidence there is suggests that the height gain (G_U) in urban and suburban areas exceeds linear. The average in these built-up areas for a 2:1 increase in height is nearer 9 dB, though there are wide variations and this statement only relates to measurements made in the range 5–10 m a.g.l. There are also indications that, especially in suburban areas, the height gain curve steepens as it passes the average roof height (about 9 m a.g.l.), at which point the antenna rises above local 'clutter' i.e., buildings and trees. This factor has a particular significance to these early results, because these were made at a time when the standard height was 30 feet (9.15 m), and height gain checks were reported for this height. It seems likely, therefore, that field strength values (U_A) should be increased by 4 dB, and this is a particularly important point because it is these measurements which were used as the basis for the Recommendation 370 curves at the shorter ranges. This would correspondingly reduce the ratio prediction/measurement of 6.3 dB shown in Table 3.

In discussing antenna height gain, reference to CCIR Report 567 is appropriate. This deals with prediction methods for mobile services, although there is not a great deal of material in the Report relating to Band I. The work so far carried out supports the thesis that it is the nature of the propagation path, and not its length, which dictates the change in field strength as either terminating antenna is raised. For heights up to 10 m a.g.l., the immediate surroundings are all-important, leading to the results in the previous paragraph – which in urban areas are higher than the figures shown in Table II of Report 567. These are average results, it seems likely that greater precision in defining the height gain in suburban/urban areas and hence deducing the field strengths at various heights of receiving antenna up to 10 m a.g.l. could be achieved by introducing some simple parameters describing the local clutter. For heights in excess of 10 m a.g.l. the terrain clearance angle correction seems to offer a useful guide, as described in Section 3.5.

Another important factor relating to the basis of the original curves must be discussed at this stage. At the longer ranges, the measured evidence came from long-distance recording (LDR) experiments, which produced field strengths at level (R_M). As described in Section 1.2, these were corrected by site variation factors (svf) to produce results for the local average terrain conditions, field strength level (R_A). This inherent inconsistency should be beneficial for planning purposes, because usually the longer range results are used to assess interference potential, and an overstatement of the field strength gives greater protection to the population, who tend to live in valleys, where the field strengths are lower.

3.5. Location variation

The variation of field strength with movement of the receiving antenna is complex, and in ordinary circumstances can only be defined statistically. As described elsewhere in this Report, this is the approach adopted in Recommendation 370, but there it is oversimplified. To pursue discussion, a simple model is considered here.

Three categories of field strength variation with location are postulated:–

(a) standing waves,
(b) clutter effects, and
(c) terrain effects.

Standing wave variation is the result of the vector relationship between the components of the signal arriving at the receiving antenna, direct from the transmitting antenna or reflected from a surface. Its extent can be observed by moving the antenna through a few wavelengths, but its assessment has not been of much interest in television survey work. It has been assumed that because such latitude or movement is usually within the individual viewer's ability to position his antenna for optimum reception, this will have been done efficiently. Measured evidence does exist to permit estimates of this effect to be made, but this has not yet been carried out.

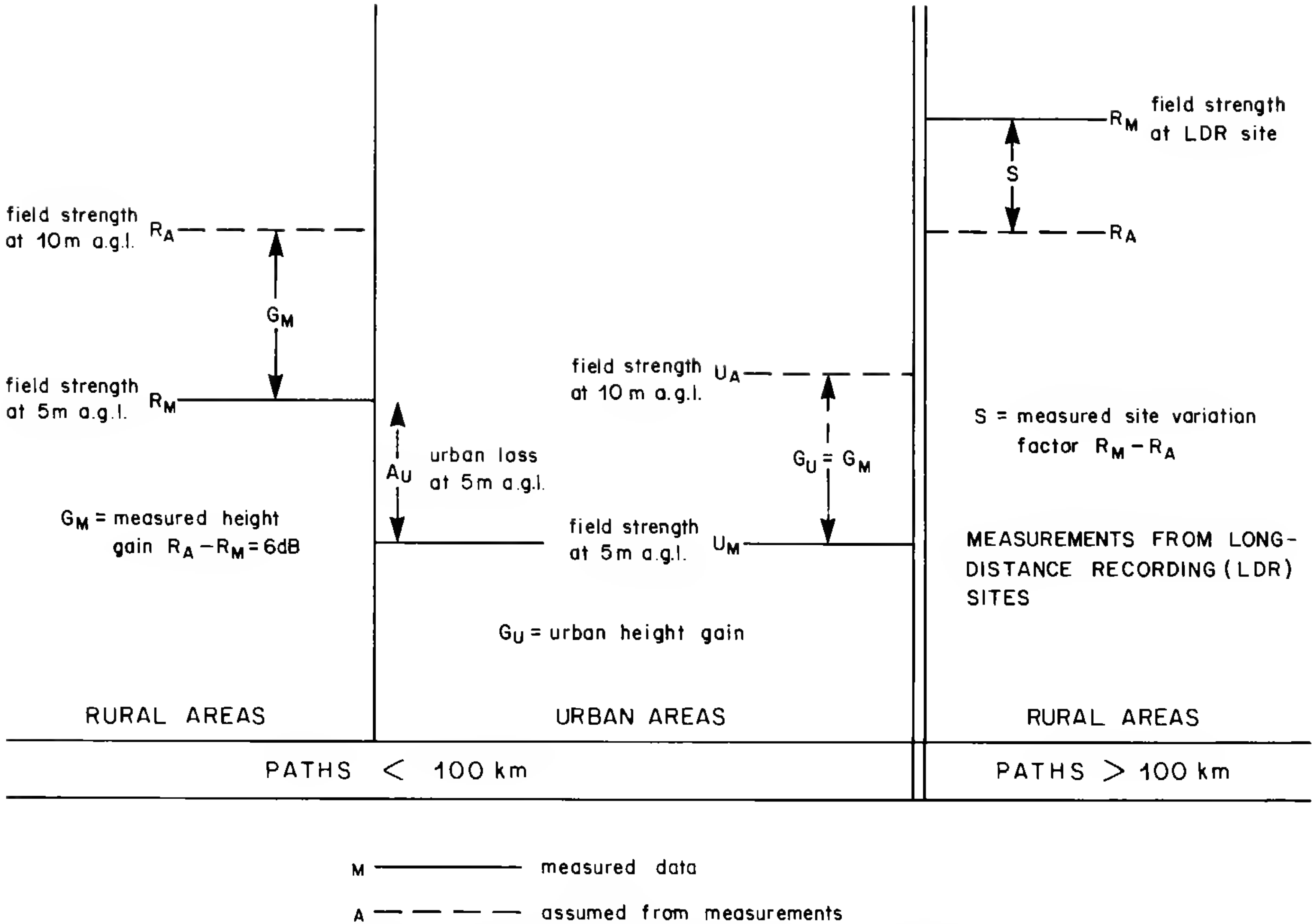

Fig. 4 – U.K. Measurement Data Used in Preparing Propagation Curves of CCIR Recommendation 370.

Variation due to local clutter will be extensive, due to the attenuation and reflection caused by the buildings and trees. The evaluation of this factor depends on the amount of information available concerning local clutter. It is apparent that a few simple items of information, such as the direction of the roads in an urban area with respect to the direction of the transmitting site, and the average height of surrounding buildings with respect to the height of the receiving antenna, could facilitate definition as in the case of antenna height gain, discussed in the previous section, and simple analysis of results from surveys carried out on the television bands gives the results shown in Table 9. Note the information shown here relating to Bands I and III has been derived from open sites in suburban areas in order to minimize the uncertainty regarding the receiving antenna height gain correction. Results for the other Bands were obtained with an antenna at 10 m a.g.l.

Frequency	Open Sites (dB)	Suburban (dB)	Urban (dB)
Band I	3	5	–
Band III	4	7	10
Band IV	7	12	16
Band V	9	14	18

Table 9 : Standard deviation of field strength in towns (flat terrain) at 10 m a.g.l.

This information was extracted from measurements in smooth terrain, in order to avoid the complication due to changes in the ground level. The results have also been simplified by assuming a log-normal distribution. This series of measurements will provide information concerning the extent of urban loss in comparison to rural measurements; this factor A_U is shown in Figure 4. At this stage numerical results cannot be quoted.

Whereas approximations of the extent of standing waves and clutter effects can be deduced with reasonable accuracy in flat terrain – and greater precision seems possible given more detail – the influence of ground irregularity upon local variation is more difficult to predict. In practice, of course, it is very difficult to distinguish betweeen the clutter and terrain categories assumed in this model. The actual situation is likely to be very confused. Furthermore, the so-called terrain effects may be due to a hill in the immediate vicinity of the receiver, or they may be caused by obstacles at some distance along the propagation path. If field strength measurement is carried out, then the environmental effects can be observed; if reliance has to be placed on prediction, then very careful analysis of topographic maps is needed. However, a good guide to the effect of terrain on the distribution of the local field may be offered by the receiver terrain correction. An illustration of this is given in Figure 5. In this figure a series of field strength measurements have been used to produce field strength contours at 10dB intervals. The same figure shows the boundaries of terrain clearance angles derived for 10dB intervals of the correction curve. This initial and brief investigation suggests that such an approach might be reasonably accurate for a first assessment — the advantage of the prediction being that it occupies a fraction of the effort and time needed for measurement. It may also be a valuable preliminary to any field work, because it gives an indication of the areas where measurements should be concentrated in order to confirm boundary conditions. As mentioned in 3.4., this correlation also seems to offer a good guide to the effect of increasing the height of the receiving antenna above 10m a.g.l.

3.6. The effects of frequency

Information from similar investigations into other bands, particularly Band II and III, will be important to a full appraisal of the prediction methods. Data such as those outlined in Table 9 confirm that attenuation increases with frequency, although at open sites there is clear evidence that field strength increases with frequency for a given e.r.p. Particularly interesting are simultaneous mobile measurements which were made of co-sited Bands I and II transmissions, which have not yet been analysed in detail. There is some evidence to suggest that field strength/distance curves for bands II and III would be about 2.0. and 3.5dB respectively above the existing CCIR Recommendation 370 curve for VHF, but much more analysis is required. The situation is confused by the receiving antenna height gain problem.

One general observation can be made concerning the occurrence of free-space fields. At UHF, these are frequently observed during measurement within service ranges of transmitting stations. and indeed the datum is a means of checking the performance of measuring equipment. Study of the Band I measurements has so far failed to reveal evidence of free-space, except under extremely short-range conditions used for equipment calibration. This can probably be attributed to the increasing significance of ground reflection at the longer wavelengths, but further examination is needed.

3.7. The effects of polarization

As with frequency, comparatively little study has yet been made of polarization effects. The

Fig. 5 – Band I Field Strength Distribution in the City of Bristol.

60 ——— Contours based on field strength measurements, shown in dB rel. 1 μV/m.

+0.3 - - - Contours at 10 dB intervals, based on terrain clearance angle correction, values shown.

majority of the measurements so far investigated were made at vertically-polarized stations, although two of the transmitters provided horizontal polarization. From the limited results available the following observations are made:–

(a) At receiving antenna heights about 5 m a.g.l. the scatter of the measured field is greater at V.P. than at H.P.
(b) V.P. has not been measured at a height of less than 5 m a.g.l. (except under calibration conditions), but at 3 m the scatter of H.P. exceeds that of V.P. measured at 5 m.
(c) There is some evidence that receiving antenna height gains in suburban areas are greater at H.P. than at V.P., perhaps suggesting that the diffraction losses are lower at V.P. This conclusion is in conflict with (a) above, and to some extent with (d) below, but a fuller analysis is required, which will need to examine the standing wave variation and the effect of multipath.
(d) In diffraction zones attenuation at V.P. is generally greater than at H.P.. except when the antenna is very close to the obstacle, when there is little difference between the polarizations.
(e) There have been many reports from Continental broadcasters that multipath interference is more severe with V.P., and the situation worsens as the wavelength increases. Various reasons have been suggested for this, the most plausible being that more vertical reflectors exist in nature than horizontal. Within the U.K. all the high-power Band I transmitters operated successfully for many years on V.P., although it is true to say that the alternative was never explored. The practical problems of producing highly-directive Band I receiving arrays probably account for the reports of certain multipath problems that therefore seem unique to those frequencies – such as phase coherent back scatter from the surface of the sea.

3.8. Sporadic E

Recommendation 370–4 does not deal with sporadic E (E_s) propagation, although there are references to Report 259 and Recommendation 534 (both CCIR Volume VI). Its absence from Section 5D is, of course, attributable to the fact that this concentrates on aspects of planning affected by tropospheric propagation, and although ionospheric transmission can cause interference to services in Band I, these effects are neglected in ordinary planning work.

Some indication of the extent of E_s propagation in Europe was gained from an experiment organised by the EBU during the period 1962 to 1972, covering an entire solar cycle. The BBC carried out much of the data processing in this experiment[6], in which five transmitters were involved – Limoges and Carcassone in France, Monte Sambuco in Italy, and Meldrum and Divis in the U.K. Measurements were made at 26 receiving sites, over paths ranging in length from 900 m to 2510 km. The location of the sites is shown in Figure 6. The main conclusions emerging from this experiment were as follows:–

(a) Solar sunspot activity has little effect on E_s propagation. It is noted here, however, that earlier work indicated some correlation exists between magnetic activity (which is related to sunspot activity) and E_s.[7,8]
(b) E_s is more apparent during spring, summer and autumn, most interference being caused during June and July.
(c) It occurs mainly during the day and early evening, peaks being reached at noon and at 1800 (times are local times at the path mid-point).
(d) Polarization of the transmission is modified by the ionosphere.
(e) The interference range of single hop transmission is from 800 to 2600km.
(f) For Band I *broadcast* planning work, where minimum field strengths to be protected are about 46dBμV/m, and protection times were generally accepted to be between 90 and 95%, interference via E_s can be neglected at frequencies above 60MHz.
(g) Maximum E_s field strengths recorded for 5% time on Northern European paths are about 20dB lower than values observed on more southerly paths. There is very little difference between 1% results.
(h) The occurrence of E_s is random and cannot be predicted with an accuracy better than ±10dB. The report describes the Miya and Sasaki prediction method, which requires a knowledge of the critical frequency of the E_s layer.

Receiving Location	Number of Complaints	Maximum Duration of Perceived Interference Minutes
Harrogate (Holme Moss)	16	10
Keighley (,,)	9	15
Blackburn (,,)	21	10
Burnley (,,)	12	10
Blackpool (,,)	28	25
Warrington (,,)	10	20
Kilsyth (Kirk o'Shotts)	2	40
Stirling (,,)	9	30
Dumbarton (,,)	4	45

Table 10 : Analysis of sporadic E complaints in Holme Moss and Kirk o'Shotts areas.

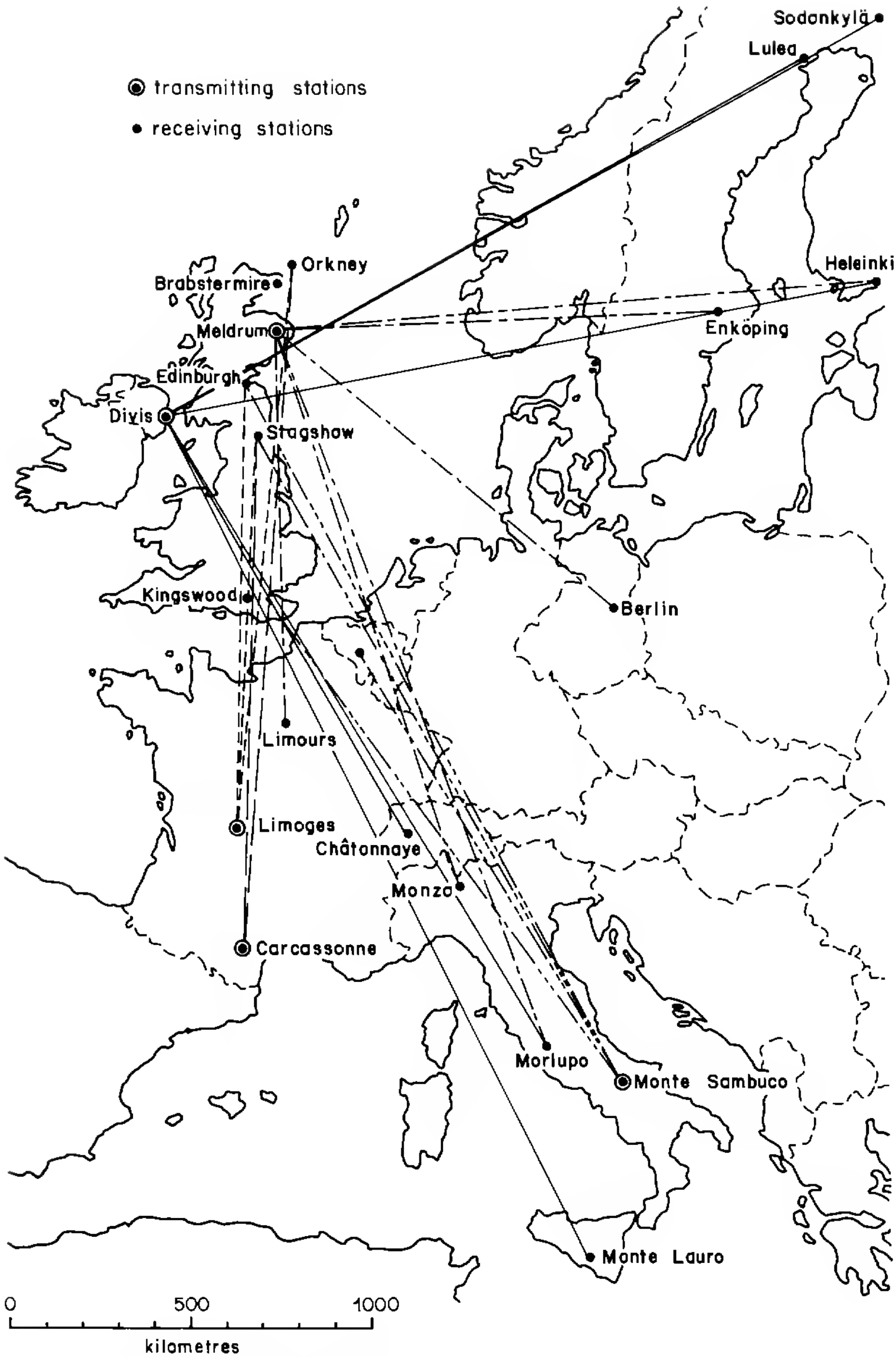

Fig. 6 – Propagation Paths in EBU Sporadic E Measurement Programme.

In addition to the EBU work, there are also 148 brief reports by BBC engineers concerning observations and measurements made following complaints of suspected E_s interference. Of the total, 111 were confirmed to be caused by this source, and Table 10 gives an analysis of the results. These suggested that the maximum field strength reached by signals from Spanish transmitters was of the order of 35–45 dBμV/m for 1 kW e.r.p. However, this deduction had to rely upon subjective assessment of the level of interference, and an assumption concerning the source of the transmissions.

The majority of the interference investigated in this particular study was caused by Spanish transmitters operating in channels E2 and E3. The most troubled locations were those in Scotland, a particularly bad site being at Dumbarton, where interference graded as definitely objectionable persisted for a period of 45 minutes.

4. Possibilities for improvement

4.1. General

This Section considers some improvements to both CCIR and BBC prediction techniques which might be achieved. In the case of the former, the work so far has identified a number of deficiencies, implying perhaps that these might cause significant errors in planning. However, it is likely that the present curves contain an inbuilt safety margin, as described in Section 3.4, and in these circumstances the deficiencies would not be apparent. To achieve greater accuracy, and hence more efficient spectrum utilisation, it is advocated that a new approach is considered for the CCIR prediction method.

In the case of the BBC technique, further development would certainly seem worthwhile. The value of a path loss method is greatest where an extensive terrain data bank is available, because obviously this should be capable of yielding better results than a statistical approach which does not take account of individual path details.

A further possibility discussed here is the reconciliation of the statistical and path loss techniques. It is suggested that basic propagation curves could be used for open country prediction, but that as more data became available describing terrain, buildings and vegetation, the precision of the calculation could be improved.

4.2. The CCIR Prediction

It is important to emphasize that the comments made here are based upon the work which has been described in this Report, and limited studies into other frequency bands. The latter would need to be extended before proposals relating to some aspects of Section 5D of CCIR Volume V could be fully described. It is suggested that the advent of extensive proposals might also be a convenient time to consider the overall structure of the present Section. It may be that a more coherent result could be obtained if the data dealing with propagation prediction at present appearing in Recommendations 370 and 528, Reports 239, 562 and 567, were combined. Supporting information appearing in those documents and Report 228 could be placed in a separate report, which would deal more thoroughly with the subject of coverage, not only for broadcasting but also for mobile services.

With regard to the prediction techniques it is important to retain the essentially simple approach adopted by the CCIR, which permits the important calculations to be carried out without the need for too much data. It is suggested that improvements could be achievd as follows:–

(a) Basic propagation curves for open country:

These would give the field strength — at 10m a.g.l. — in an open country. Evidence for these curves would be extracted from existing measurements made in areas which are within line of sight of the transmitting antenna (for those paths beyond the optical horizon, see below), and the study would include the significance of polarization, ground reflection, and the question of free-space propagation. The method of determining the effect of changing the height of a terminating antenna requires further study; the technique of using a terrain clearance angle for both ends of the propagation path appears very promising. It is essential that in the development of any new technique, the need for terrain data is borne in mind. Complex proposals could be prepared assuming that a highly sophisticated terrain data bank is available, but this would defeat the main objective of retaining a simple approach. Therefore any new method should not seek substantially more data than are needed at the present time to achieve proper use of the curves.

(b) Curves for longer ranges:

These would extend beyond the curvature of the earth, and would be an extension of the curves produced in (a), i.e., they would represent open country conditions. The review described in this report has commented on the paucity of measurements, but it is recognised that such experiements are extremely costly and time consuming. Means should therefore be explored of making the most of available measurements. In the case of the BBC experi-

ments, rather more than 50% of the original data still exist in adequate detail to permit fuller analysis. As far as basic measurements are concerned, it seems likely that a more realistic conversion from the measured result to the 50% location figure would be obtained using the terrain clearance angle. It may be possible to include 0.1% time values, and certainly a determined attempt should be made to weight individual experiments in terms of their durations. This would require correlation against some datum, such as might be extracted from basic meteorological reports for the areas measured and for the time of the experiment – it is understood these are still available. There is much to be learned here by comparison with similar work in other frequency bands.

Consideration might also be given to including ionospheric propagation in addition to the tropospheric components.

(c) Local variation – flat terrain:

The objective here would be to devise corrections for application to the open country curves which would take account of –

Urban/suburban losses
Receiving antenna height gain
Clutter effects

These effects are closely related; the ability to distinguish between them, and the precision of any correction, will depend on the detail available. For example, it is quite easy to propose a simple correction which would take account of urban losses, i.e. the attenuation experienced when moving from the environment of the open country to that of a town. However, if a fuller appreciation of the coverage of a mobile service is required, then it is useful to consider the directions of the streets with respect to the bearing of the transmitter. Similar detail affects the determination of the receiving antenna height gain. Various ideas exist for pursuing this work, using existing measurements. However, there is certainly a shortage of height gain information at Band I. Some further field work may also be needed to explore the influence of polarization.

(d) Local variation – effect of terrain:

This would be a correction to take account of terrain in the immediate vicinity of the receiving antenna. Much work has been done on the terrain clearance angle idea, and further development leading to simplification seems very possible. This could offer a most worthwhile improvement in prediction accuracy.

4.3. The BBC path loss prediction

As described in Section 1.3.2. this program was originally developed for use at UHF, and a high degree of accuracy was achieved. It is informative to quote a comparison in which the standard deviation of a distribution of CCIR predictions compared with measurements was 13.6 dB, and the equivalent result for the BBC program was only 7.3 dB. However, at lower frequencies the results so far achieved have not been so impressive. Nevertheless, the success at UHF, some progress at VHF Band II, and the existence of a terrain data bank argue the case for more development.

Three possible routes could be considered:–

(a) Retain method, but re-optimize parameters to take account of different frequencies.
(b) Retain concept of present prediction, but develop new elements which would not only address the requirement for frequency mobility, but would also eliminate known shortcomings of the present program.
(c) Adopt completely new approach.

In terms of effort, (a) would require the least, (c) the most. The parameters mentioned in (a) relate to clutter losses, and to interpolation factors used in defining the profile for a particular path. This approach has been adopted in extending the present program to Band II, but other deficiencies remain, although there are ideas for dealing with these. Option (c) is not promising and for this reason (b) appears to be the solution capable of offering the best results for a moderate investment of effort. It also seems likely that some of the work required would be closely related to, if not the same as, that needed for some aspects of the harmonised proposal made in the next sub-section.

4.4 A combined prediction technique

The methods described above are independent – the CCIR is a statistical approach requiring little data to achieve a prediction, whereas the path loss technique needs a comprehensive data bank. The possibility is put forward that the two could be reconciled, that the basic curves could be used for open country prediction, but that as more data became available describing terrain, building etc, the prediction could be improved to relate to precise receiving locations. Such an approach would encourage international co-ordination in the development of more precise techniques, based on a common system.

The key to such a development lies in the data needed to perform the calculation. It seems likely that the terrain angle approach might be developed for use also at the transmitting end, as discussed in Section 4.2., but this would have to be achieved without a substantial increase in the amount of data required to define the present height above mean terrain. The availability of additional data would

enable greater precision to be achieved not only in defining the overall profile, but also in determining the effect of the various correction factors, e.g. for defining the location variation, and clutter effects.

5. Conclusions

The work described in this report is based on an analysis of Band I field strength measurements, most of which were made by the BBC. Many were originally used as evidence in compiling CCIR propagation curves which have been used for spectrum planning purposes for the past 25 years. Computer techniques have permitted a fuller analysis of these measurements than has previously been possible, and the conclusions listed here have been drawn on the output so far obtained. The opportunity has also been taken to review the value of the BBC path-loss prediction program for work in Band I, and the possibility of reconciling this technique with the simpler CCIR approach has been identified.

The detailed conclusions are as follows:-

(a) For path lengths of up to 100 km, the VHF curves of CCIR Recommendation 370 appear to overestimate median values of measurements made in towns by an average of 6.3 dB. However, the use of an open-country receiving antenna height gain to correct measurements made at 3 to 5 m a.g.l. in towns underestimates the field strength existing at 10 m a.g.l. in such areas. This underestimate probably amounts to 4 dB, which would reduce the discrepancy between the CCIR VHF curves and the corrected measurements to about 2 dB. It is therefore concluded that the present CCIR VHF curves in Recommendation 370 overestimate Band I field strengths at 10 m a.g.l. in suburban areas by this amount.

(b) For ranges in excess of 100 km, the comparison between CCIR prediction and measurement reveals close agreement. There is no confusion concerning receiving antenna height gain correction, because most of the measurements were made with the antenna at or near 10 m a.g.l. However, there is a comparatively small amount of measurement for these longer ranges.

(c) There is an inconsistency in the Recommendation 370 curves in that at the short ranges they are based on measurements in urban and suburban areas, whilst at longer ranges the evidence is drawn from experiments in open country. The former are attenuated by urban clutter, and in many cases by terrain, because most of the towns measured are situated in valleys. The overall result – understating service area field strengths relative to those for the longer ranges – may have provided a 'safety margin' for planning purposes. However, if maximum usage of the frequency spectrum is to be achieved, this apparent inconsistency must be resolved.

(d) There are, as yet, insufficient results to give reliable figures describing the relationship of measurements in Band II and III to the CCIR curves, but limited evidence suggests that here the prediction will underestimate the field strength. Enough data exist to produce separate curves for the three VHF bands, and further work is recommended.

(e) Having re-examined in some depth most of the original U.K. data used in the construction of the CCIR curves, it is concluded that the best solution would be a new approach, whilst observing the vital requirement that any new technique should be as easy to apply as the present curves, and make no excessive demands for data e.g. terrain details. Paragraphs (f), (g) and (h) below are offered in support of this conclusion.

(f) The means of defining the effect of transmitting antenna height (i.e. above mean terrain) in the existing CCIR curves appears ineffectual. The terrain clearance angle concept appears to offer a better solution, certainly for Band I, and further research using this approach is recommended.

(g) The definition of receiving location given in CCIR Recommendation 370 requires clarification. The assumption of log-normal distribution, unrelated to any statement concerning the size or nature of the area represented is an extreme simplification. This aspect is influenced by the extent of the movement of the receiving antenna, the direction (in any plane), the propagation path, the environment, the frequency and the polarization. The work so far suggests that various simple corrections can be devised to take account of clutter losses, local terrain, and receiving antenna height gains, although the amount of information concerning the latter is very limited. Further work is required on the influence of frequency and polarization.

(h) Similarly, the definition of time variation needs clarification. Existing measurement data could be re-analysed to obtain worst-period statistics. The possibility should be explored of establishing a link with weather statistics to facilitate this, and weight existing results in terms of the duration of each experiment. In view of the very limited number of experiments, further measurement programmes are recommended.

(i) The programme of work conducted into the Band I results should be repeated using measurements obtained in other VHF/UHF bands, in order to produce a coherent result for this part of the RF spectrum.

(j) Consideration should be given to revising the format of the whole of Section 5D of CCIR Volume V.

(k) The BBC path loss prediction programme should be examined with the objectives of extending

its frequency range and eliminating the generally minor existing problems.

(l) The possibility of reconciling the two distinct prediction techniques (CCIR and path loss) should be explored, and in this context there is a need to examine the terrain data requirements on an international scale.

6. Acknowledgement

The work described in this report was undertaken jointly for the BBC and the UK Department of Trade and Industry. The useful discussions with engineers of the DTI Radio Regulatory Division during the project are gratefully acknowledged.

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Appendix – a summary of the BBC path loss prediction.

The operation uses a terrain data bank, based on a 0.5km grid, but having the facility to accept alternative more detailed information. Each unit of the grid contains a ground height representative of the square, and 'clutter' (building and tree) information. Certain additional information, such as population density and coverage details, are also included on the same grid for planning purposes.

Having extracted the terrain profile for the selected propagation path, the program forms an approximation to this which has simple geometry, amenable to existing calculation techniques. The most obvious approximation is to assume that the profile consists of a few knife edges, simulating the most significant hills, but experience shows that where multiple edges are concerned, this alone tends to overestimate the field strength. An alternative is to approximate the profile to a smooth surface, having a rounded shape. This produces an underestimate, and an empirical interpolation between the two profile models, gives a satisfactory result.

(1) The Knife-edge Approximation:

The multiple knife-edge loss calculation is based on a method by Deygout (reference A1), but with corrections. The method may be applied to paths containing an unlimited number of edges, although in the BBC program a limit of three is imposed, and the construction is as shown in the Figure A1.

The loss for each edge is first calculated as if all other edges were absent. The edge h_1 producing the great loss A_1, divides the path into two sections which are then considered separately. The edges h'_2 and h'_3 are then calculated, giving attenuations A_2 and A_3 respectively. The total path loss is the sum, in decibels, of the three. Deygout discovered that this method always overestimated the loss, and a correction for this has been devised and is included in the program.

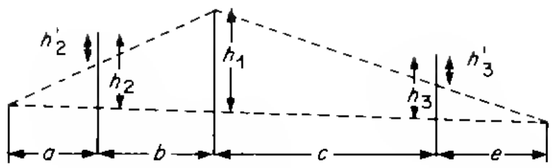

Figure A1 : Geometrical construction for the Deygout method

(2) The Smooth-Surface Approximation:

In the multiple edge situation, this approximation is achieved using the Longley and Rice technique (reference A2).

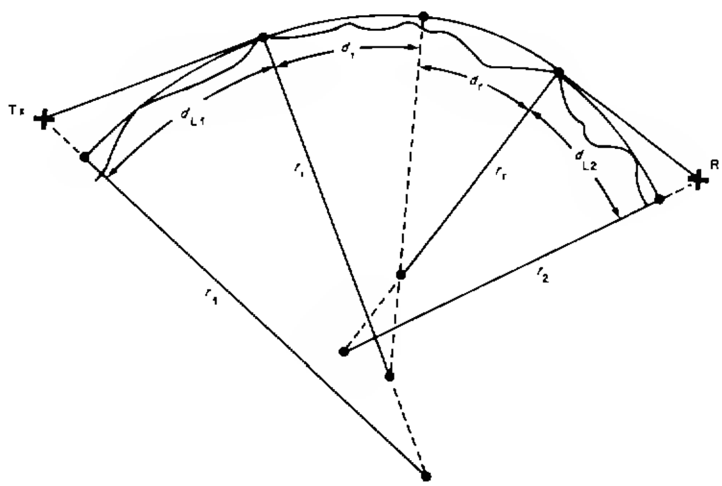

Figure A2 : Geometry for curved-surface diffraction calculation

This uses four radii, and the geometry is shown in Figure A2. Radius r_1 is of a cylinder which has the horizon line of the transmitter Tx as a tangent, and the terrain between this tangent point and the terminal is just enclosed by the cylinder. Radius r_2 is similarly determined. Then the values of r_t and r_r arise from the requirement that there shall be no slope discontinuities at the junctions between the surfaces. This requirement also determines the value of d_t and d_r. From this, the loss over a spherical surface is given by

$$As = G(x_0) - F(x_1) - F(x_2) - 20$$

where $x_1 = 448\lambda^{-1/3} r_1^{-2/3} d_{L1}$

$x_2 = 448\lambda^{-1/3} r_2^{-2/3} d_{L2}$

and $x_0 = 448\lambda^{-1/3}(r_t^{-2/3} d_t + r_r^{-2/3} d_r + r_1^{-2/3} d_{L1} + r_2^{-2/3} d_{L2})$

In the case of a single edge, the smooth surface is approximated by a wedge shape, as shown in Figure A3.

The diffraction edge corresponds to the peak of the wedge, which will be coincident with the edge visible to both terminals, or a virtual edge produced by the projection of the horizon lines. The four-ray method is then used to calculate the diffraction loss.

In the case of an optical path it is considered that to produce a surface the most relevant criterion is that it

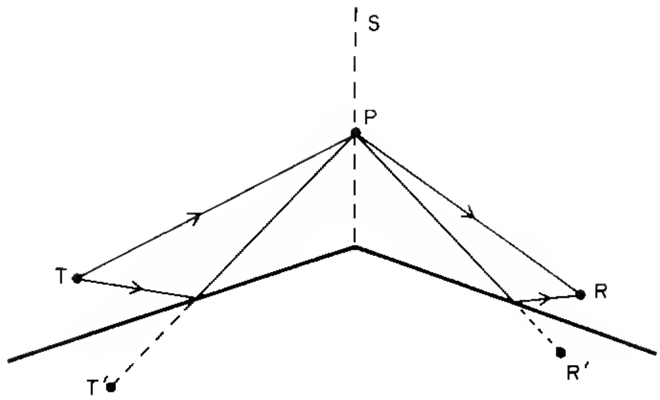

Figure A3 : Wedge diffraction

shall have a minimum path difference which is the same as the minimum path difference produced by the actual ground. The surface should pass through the ground heights at transmitter and receiver in a manner similar to that for the multiple edge condition. but in this case the edge giving minimum clearance dictates the section to be taken rather than the horizon. A single circle may then be constructed which passes through the end points and touches (common tangents) the ellipse produced by the locus of points having the same minimum path difference as that of the actual ground. The construction is shown in Figure A4.

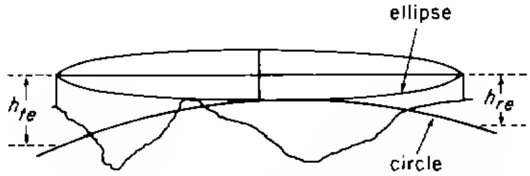

Figure A4 : Surface for an optical path

(3) Interpolation Between Knife-edge and Smooth-Surface Losses:

Given the results of the two sets of calculations, for a diffracted field, the end result is computed by interpolation. An empirically derived factor ω is used for this purpose to produce the diffraction loss A_D, thus

$$A_D = \omega A_K + (1-\omega)A_s$$

where A_K = Knife-edge attenuation
A_s = Smooth surface attenuation

Reference A1: Deygout, J. 1966 Multiple knife-edge diffraction of Microwaves" IEEE Trans. Antennas and Propagation, 1966. AP–14, 4, pp. 480–489.

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